Purdue University – CHE 37800
Chemical Engineering Fundamentals Laboratory

Diffusive Mass Transfer

Objectives

Analyze the equimolar counter diffusion between CO_2 and N_2 initially maintained in separate containers. Calculate the binary (N_2-CO_2) diffusion coefficient through the application of *Fick's 1st law of diffusion* and the use of the quasi-steady-state approximation.

Experimental setup

One of the simplest experimental setups for the study of diffusion is the one proposed by Graham and Loschmidt and consists of two gas containers of equal volumes connected by a capillary tube. Recirculation loops, or internal fans, keep the two containers well-mixed. Initially the tube connecting the two containers is kept closed while both tanks are filled with the respective gases (N_2 and CO_2). The pressure in both tanks is maintained at atmospheric pressure. To start the experiment, the capillary tube is opened so that the gases can diffuse freely. The concentration of CO_2 in the container initially filled with N_2 is monitored as a function of time. From these data, the binary (N_2-CO_2) diffusion coefficient can be determined. Most of the traditional setups to study diffusion involve time consuming experiments. The current setup allows gas phase diffusivity to be studied on shorter time-scales, where the tube length, cross-sectional area and the volumes of the two containers have been designed for this experiment. The volume of each container is 1 liter, and the length of the capillary tube and its inner diameter are 159 mm and 4.572 mm, respectively.

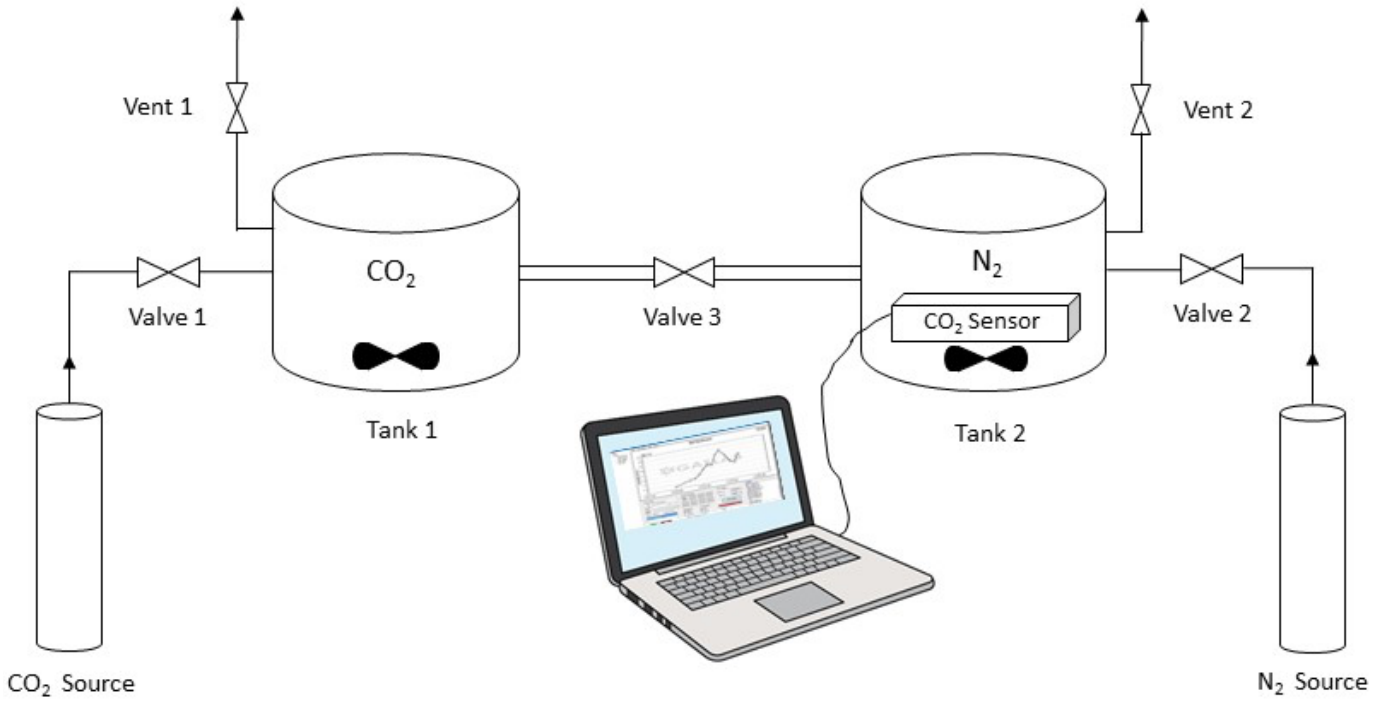

Figure 1. Schematic of experimental setup.

Running the experiment

Follow the experimental procedure you developed in the pre-lab activity. If you find as you perform the experiment that modifications are needed and/or some details are missing from your procedure, incorporate those changes into an updated protocol. (Your final protocol must be described in your lab report/presentation.)

Precautions:

- To ensure that there is no convective mass transfer between the two containers, the pressure must be uniform throughout the system.
- Before beginning a given trial, the entire setup must be purged with nitrogen before charging the vessels with the appropriate pure gases to ensure that there are no residual gases in the setup (i.e., no CO_2 initially in Tank 2 and the adjacent portion of the connecting tube).
- To keep the gas concentrations in each tank homogeneous, there is a small fan at the bottom of each vessel. These need to be turned on.

Before each trial, Tank 1 should contain pure CO_2 while Tank 2 should contain pure N_2. First, Tank 2 is purged with N_2 and then N_2 is blown through the tube and Tank 1. The two tanks are then isolated again (Valve 3 is closed) and filled with the corresponding gases. When charging gas into the system, keep in mind that **the vents need to be open** so the gas will not pressurize the tanks. You will use a **CO_2 Meter CM-0039 sensor** to measure in real time the concentration of CO_2 in Tank 2.

Initial State: All valves are closed, and the tank fans are operating.
Note: Vent 1 and Vent 2 are open when the longer part of the valve handle points towards the tank and the pointy part points away from the tank.

Step 1: Setting up real-time CO2 concentration measurement

1. On the laptop find and launch the program "**Gaslab2.1**"
2. In the section "Sensor Select":
    a. In field "Product" select "CM-0039"
    b. In the field "Port" choose the option shown, (e.g.: "COM3")
    c. Click "Connect"
3. In the section "Auto-Logging" check that you have selected "every 30 seconds" and "for 1 hour"

Step 2: Nitrogen Purge

1. Open Vent 2 and Valve 2.
2. Wait 2 minutes to allow N_2 flow to purge Tank 2.
3. Open Vent 1 and Valve 3. Make sure Valve 1 is closed.
4. Close Vent 2.
5. Wait 1 minute to allow N_2 flow to purge the capillary tube and Tank 1.
6. Open Vent 2 and close Valve 3. This ensures that the two tanks are separated from each other and are open to ambient air.

Step 3: Initial Gas Charge

1. Open Valve 1 (Valve 2 is open from Step 2).
2. Wait 2 minutes to allow each tank to fill with the appropriate gas.
3. Close Valve 1 and Valve 2.
4. Wait 4 minutes to allow the pressure in each tank to reach ambient pressure.
5. Close Vent 1 and Vent 2.

Step 4: Data collection

1. In GasLab2.1 program click "Configure Sensor" in the section "Sensor Commands"
2. Click "Calibrate to zero", then close this "Configure sensor" window
3. Click "Start logging" in the section "Auto-Logging" and choose a name for your file. Your data will be saved in the "**GaslabLogs**" folder (shortcut on the desktop).
4. Slowly open Valve 3 and start monitoring the change in CO_2 concentration in tank 2.
5. Start the timer and record CO_2 concentration during diffusion for 20 minutes.
6. Click "Stop Logging" and close Valve 3.

Repeat experiment 2 more times (Steps 2 – 4) and save your data as "**Append File**" for the second and third trial. Retrieve your file from the "GaslabLogs" folder before leaving the lab.

Laboratory Activity

The following should be done during the Lab period and included in your lab report (in an Appendix):

An exact transient analysis of this system yields an infinite series solution, which after some sufficiently long time ($Dt/L^2 >\approx 0.3$) indicates that the concentration of CO_2 in Tank 2 will vary according to

$$\frac{1}{2+\alpha} - \frac{c^{(2)}}{c_0} = a_1 \exp\left(-\frac{\lambda_1^2 Dt}{L^2}\right)$$

Where:

$$\alpha = \frac{tube\ volume}{container\ volume}$$

$$\frac{c^{(2)}}{c_0} = \frac{concentration\ of\ CO_2\ in\ Tank\ 2}{initial\ concentration\ of\ CO_2\ in\ Tank\ 1}$$

L = Length of capillary tube D = binary diffusion coefficient a_1 = constant

and λ_1 is the smallest positive root of the following equation

$$\tan\lambda = \frac{2\alpha\lambda}{\lambda^2 - \alpha^2}$$

Show that the use of the quasi-steady-state approximation is well-justified for this experimental setup.

Laboratory Report/Presentation

Present and discuss your experimental results. Compare your resulting value of D to what appears in the literature. Additional details and report/presentation requirements are provided in the corresponding lab report/presentation guidelines.

References

- Ramkrishna, D., and Amundson, N. R., *Linear Operator Methods in Chemical Engineering with Applications to Transport and Chemical Reaction Systems*, Prentice Hall, New York, 1984.
- Bird, R. B., Stewart, E., and Lightfoot, N., *Transport Phenomena*, 2nd ed., Wiley, New York, 2002.
- Cussler, E. L., *Diffusion: Mass Transfer in Fluid Systems*, 2nd ed., Cambridge University Press, Cambridge, UK, 1997.